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Determining the Mass of the Top Quark with the SDC Detector

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We report a technique to accurately determine the top quark mass by reconstructing the mass of the three jets from top quark decays. We are interested in $t\bar{t}$ events in which the top quarks decay via $t \to Wb$ followed by one W decaying to $\ell\nu$ while the other W decays to two jets. We have taken top quark masses of 150 and 250 GeV/c^2; in the discussion below, values corresponding to 250 GeV/c^2 are shown in parentheses. Additional details of this technique can be found in Ref. 1; an alternative but similar approach is described in other SDC notes, Ref. 2. The study reported here has employed Isajet 6.31. The detector was not simulated in detail. Instead, the energy and momenta of tracks and jets were smeared with the assumed resolutions. We trigger by requiring an isolated electron or muon (ℓ) with $p_t > 40$ GeV/c and $|\eta| < 2.5$. The efficiency for this trigger (including an 85% efficiency for identifying leptons) is $e_{\ell-trig} \simeq 0.30$ (0.42 for the $M_{top} = 250$ GeV/c^2 case). We further demand two tagged b-jets with $p_t > 30$ GeV/c within $|\eta| < 2.0$. The efficiency for tagging both the b-jets through secondary vertices (discussed in Ref. 3) is $e_{b-tag} \simeq 0.07$ (0.12) (including the above-mentioned transverse momentum and rapidity requirements). With these trigger and tagging efficiencies, the number of resulting events per SSC year is $2N_{t\bar{t}}B(W \to \ell\nu)e_{\ell-trig}e_{b-tag} = 1.1 \times 10^6$ (3.4×10^5) (where $N_{t\bar{t}} = 1.2 \times 10^8$ (1.5×10^7) is the total number of $t\bar{t}$ events per year).

Next we attempt to identify the two non-b jets coming from the hadronic decay sequence, $t \to bW \to bu\bar{d}$ (or $bc\bar{s}$), of the top quark opposite the trigger. Jets are formed by clustering final-state particles appearing in the region $|\eta| < 3.0$ within a cone of radius $R < 0.6$. The 4-momenta of these jets are then smeared with an assumed jet resolution of $70\%/\sqrt{E} + 3\%$ to conservatively account for the SDC calorimeter resolution[4] ($50\%/\sqrt{E} + 3\%$) as well as effects due to clustering (the results are rather insensitive to the resolution, but are sensitive to jet clustering effects[2]). Any two non-b jets within $|\eta| < 2.5$ and having $p_t > 20$ GeV/c are then used to form invariant mass combinations. Most events will contain additional jets due to initial- and final-state radiation. We find using Isajet that the average number of non-b jets reconstructed with $|\eta| < 2.5$ and $p_t > 20$ GeV/c is about 3.1 (3.6). If one examines the invariant mass distributions for all pairs of non-b jets in our events in an attempt to see the mass peak from the hadronic W decays, a substantial combinatoric background is evident, as illustrated in Fig. 1, arising primarily from dijet selections in which one or both of the jets arise from the secondary radiation processes. The relative number of non-$t\bar{t}$ events from continuum production of $Wb\bar{b}\ jet\ jet$ selected by the trigger and passing the additional requirements has been found to be less than a tenth of a percent.[5]

A very effective technique for reducing this combinatoric background is to restrict our dijet invariant mass plot to the two (non-b) jets with the highest transverse momenta that in combination with one of the tagged b jets yield a net three-jet invariant mass (M_{jjb}) smaller than 300 GeV/c^2 (for $M_{top} = 250$ GeV/c^2, we used $M_{jjb} < 400$ GeV/c^2). Of course if we found a mass peak close to 300 GeV/c^2, we would modify this choice. This technique will eliminate a significant number of incorrect combinatoric choices involving radiatively generated jets or the wrong b jet. By "highest transverse momentum", we mean an algorithm in which we chose the leading p_t jet, and then searched for the remaining jet with the highest p_t such that the 3-jet mass was less than 300 GeV/c^2. If none satisfied this criterion, we began with the next-to-leading jet and again searched the remaining jets (and so on). This distribution is also plotted in Fig. 1. The combinatoric background has been severely reduced by only plotting one combination per event, and the above choice tends to be the correct one.

Finally, to reconstruct the top quark mass we take all events in the W mass interval of the heavy solid histogram of Fig. 1 ($60 < M_{jj} < 100$ GeV/c^2). The two jets used to plot the dijet invariant mass are then combined with one of the tagged b jets, and the invariant mass of the dijet-b combination is computed (this is done for both b jets in the event). Because of our procedure, the 3-jet mass is guaranteed to lie below 300 GeV/c^2 for at least one of the b-jet choices. The resulting 3-jet invariant mass distribution is plotted in Fig. 2 . Remarkably sharp mass peaks are evident, centered about the top quark masses of 150 and 250 GeV/c^2. Because of the large number of events retained by this procedure, and the reduction of the combinatoric background by our techniques, we find that the top mass can be determined statistically to ± 75 MeV/c^2 (± 200 MeV/c^2 for M_{top} = 250 GeV/c^2). The actual accuracy of this measurement is limited by systematic errors due primarily to the energy measurement of jets. Assuming that one will do somewhat better than the CDF experiment, we might expect $\pm$2-3% accuracy ($\pm$3-4 ($\pm$5-7) GeV/c^2) depending on theoretical uncertainties. In conclusion, this direct technique will yield a top mass measurement that is as good as or better than other techniques, depending on the actual systematics.

REFERENCES

1. R.M. Barnett *et al.*, SDC note SDC-90-00141
2. P.K. Sinervo, R.J. Hollebeek, and H.H. Williams, SDC notes SSC-SDC-30, SDC-90-00114 and SDC-90-00117
3. B. Hubbard, SDC note SSC-SDC-31
4. I. Hinchliffe *et al.*, SDC note SSC-SDC-100.
5. Private communication from Edward Wang.

FIGURE CAPTIONS

1) The invariant mass distribution for non-b dijet combinations, for $t\bar{t} \rightarrow WWb\bar{b}$ events. All two-jet combinations are included in the light solid histogram. The heavy solid histogram retains only the *highest transverse momentum* (see text) jet pairs with $m(\text{dijet} + b) < 300$ GeV/c^2. Each plot has the same number of events, but the light histograms have additional combinations. The top masses assumed are (a) 150 and (b) 250 GeV/c^2.

2) We plot the 3-jet invariant mass distribution, where two of the jets are the 'highest transverse momentum' non-b jets with dijet mass in the W mass interval, and the third jet is a tagged b jet. The top masses assumed are (a) 150 and (b) 250 GeV/c^2. The number of events generated for this plot is about 1% of that expected for a standard 10^4 pb^{-1} SSC year.

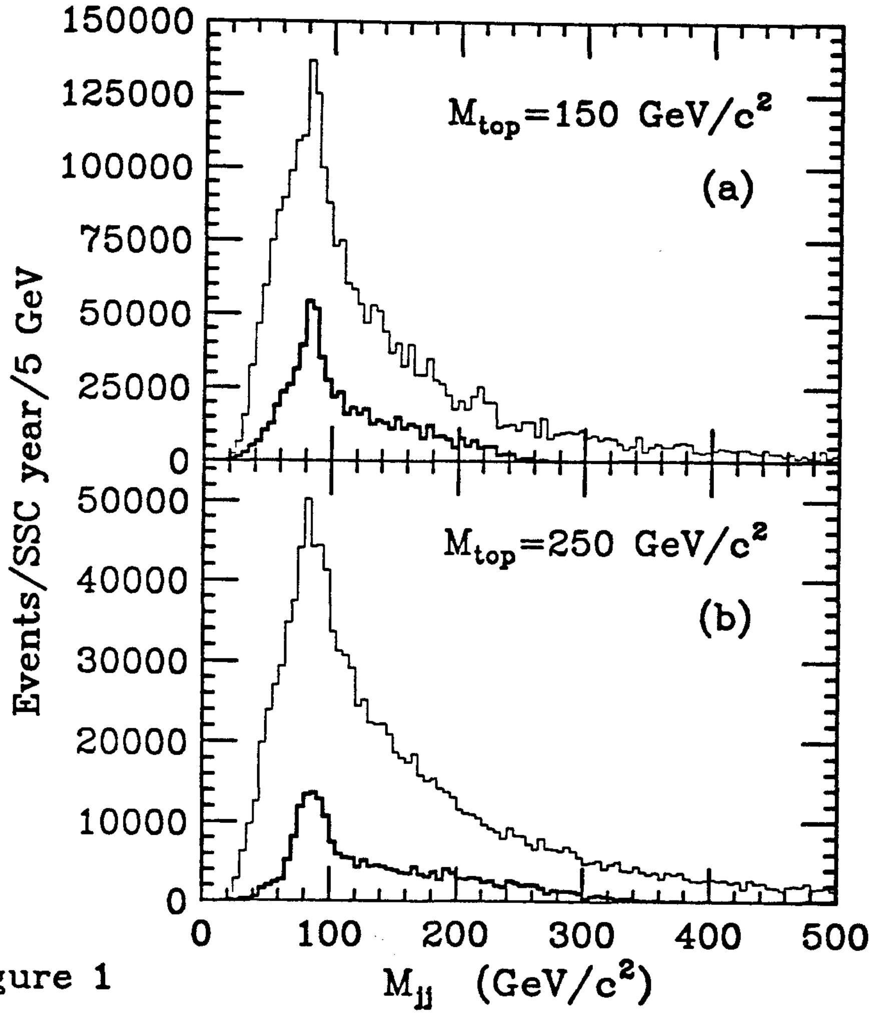
M_{top}=150 GeV/c^2
(a)
M_{top}=250 GeV/c^2
(b)
Events/SSC year/5 GeV
M_{jj} (GeV/c^2)
150000
125000
100000
75000
50000
25000
0
50000
40000
30000
20000
10000
0
0
100
200
300
400
500

Figure 1

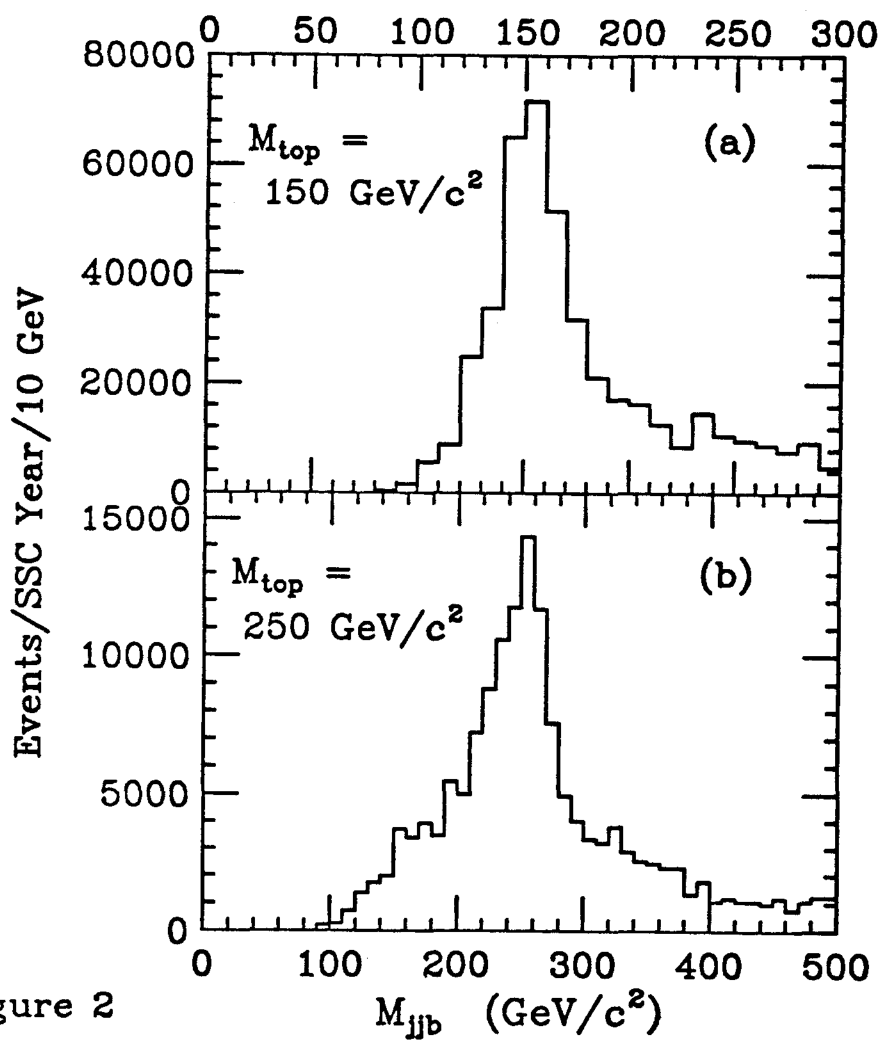
0 50 100 150 200 250 300
80000
60000
40000
20000
0
15000
10000
5000
0
M_{top} =
150 GeV/c^2
(a)
M_{top} =
250 GeV/c^2
(b)
Events/SSC Year/10 GeV
0 100 200 300 400 500
M_{jjb} (GeV/c^2)

Figure 2